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Liquid Impedance Analyser for Glucose Concentration in Water using Resonance Model

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Abstract. Liquid impedance measurement systems are widely developed as a promised method for analyte detection. The system was using a capacitive model. The object was modeled as a capacitance which then related to the analyte permeability. In this study, a full impedance model formed from the capacitance, inductance and resistance property of the analyte was used. The model which then called an RLC model was constructed in which the analyte properties affect the capacitance, inductance and resistance value of the model at any given frequency. A resonance frequency of the model was exists based on the resistance, capacitance and inductance value. A mixture of water and glucose was used as a measurement model. The impedance spectrum of the RLC model was related to the glucose concentration in water. It was found that the resonance frequency of the system.

1. Introduction

Electrical impedance is composed of a resistive and reactive property of the electrical circuit system. Impedance occurs when an alternating current is applied to the circuit. The resistance and reactance of the system depend on the material property where the electrical current is applied. Resistance is the result of the electrical conductivity, whilst the reactance exists when a capacitance or inductance exists in the system. An impedance always exists in any electrical system in any form of an electrical circuit. It is also known that the electrical reactance, and then the electrical impedance value of the system is also frequency dependent [1].

The capacitance value depends on the permittivity, and the inductance value depends on the permeability of the materials where the capacitive element and inductive element are formed. As such by constructing a specific electrical model, the permittivity, the permeability, and the conductivity of a specific material in a specific geometrical form can be measured. The combination values of those three electrical properties can be used for material identification or composition. However, the system should be designed to eliminate the effect of the frequency of the electrical signal applied to the system. For a system filled with liquid, the impedance can be attributed to the liquid properties and the construction of the electrical element.

Figure 1 shows the most typical electrical circuit (EEC). The circuit consists of a resistor and a constant phase element (CPE) arranged in series, and capacitors arranged in parallel [2] [3] [4].

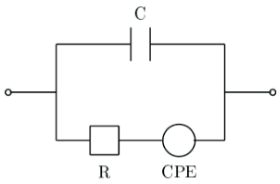

Figure 1. Schematic model of equivalent electrical circuit (EEC)

The electrical circuit in Figure 1 can be formed by using a capacitive, inductive and resistive device which was originated from glucose in water. The impedance value of the circuit can be measured using an impedance analyzer. It was known that the permittivity (ε_h) is decreased as the concentration of glucose increased and conductivity is increased as the increase of glucose concentration in water solution [5]. Therefore we can expect that the impedance value of any circuit formed by a device containing glucose in water can be measured.

Many impedance-based measurements were done by forming a resistive and capacitive part [2]. In our study, the glucose in water detection was done by constructing an RLC circuit model where the resistive, capacitive and inductive part was determined by the glucose concentration in water. By selecting the correct value of the RLC part, the model has series and parallel resonance frequencies which depend on the RLC value. By the fact that the capacitance and inductance values are affected by the solution permittivity and permeability, detecting the series resonance frequency, and the impedance spectrum can be used as the tool to analyze. The purpose of this study was to determine the effect of changes in the value of permeability and permittivity of the material to changes in frequency response and to determine the concentration of glucose in water through changes in series resonance frequency and the impedance spectrum.

2. Model Development of Liquid Impedance Analyser

2.1. The RLC Circuit Model

The simple RLC Circuit as shown in Figure 2 was used as the circuit of our developed impedance analyzer which can simplify the process of determining the impedance of the analyte. The model was derived from the physical design which contains a capacitor with the liquid as the dielectric material, an inductive with the liquid inside the inductor and a resistive part. The impedance part Z_1, which was composed of the liquid property, was formed from the physical design of the measurement system which contained a capacitive and inductive elements.

$$Z_1 = R + X_C + X_L \quad \text{.... (1)}$$

$$Z_{total} = \frac{Z_1 . Z_{C2}}{Z_1 + Z_{C2}} \quad \text{.... (2)}$$

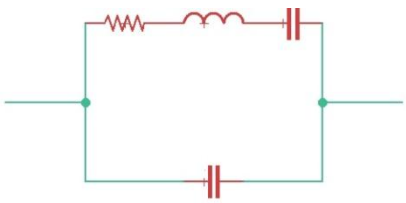

Figure 2. Equivalent circuit for liquid impedance analyser

2.2. Impedance value calculation

The simulation was done according to the dimension of the measurement system which contained the resistance, capacitance, and inductance. A calculation using a MATLAB was conducted to find the dimension of the system in a range of measurable resonance frequency using the available impedance analyzer. The expected range of the resonance frequency should be less than 10MHz.

In the design, the resistance value was obtained from liquid resistivity value, and the inductance was acquired from the liquid permeability value and the twisted number of wired, then capacitance based on the liquid permittivity and the parallel plate geometry. It was assuming that the water resistivity, permeability, and permittivity was independent of frequency. The electric and magnetic property of water is resistivity (ρ) = 10KΩ/m, permeability (μ) = 1.256×10^{-6} and permittivity (ε) = 7.17×10^{-10} [5]. The theoretical values of the physical model with the liquid contained water are $L = 1.30 \times 10^{-5}$ H, and $C = 2.17 \times 10^{-11}$ F.

3. Result and Discussion

Calculation based on the model was done by varying the glucose concentration in water. Increasing glucose content in water changes the permittivity and permeability of the solution of the glucose in water. In this model, we are assuming that the change of the permittivity and permeability was a simple linear model related to the fraction of the glucose and water in the solution. As the permeability and permittivity of the glucose are lower than the water, increasing the glucose concentration results in decreasing value of the capacitance and inductance. The change of the capacitance and inductance leads to the change of the impedance value.

Figure 3 shows the impedance spectrum of the model with varying glucose concentration. It can be seen that the resonance frequency of the model was increased with the increase in glucose concentration. Both of the series resonance and parallel resonance increased. The maximum impedance value which related to the parallel resonance frequency decreased with increasing parallel resonance frequency. It was caused by the change of the capacitance and inductance value of the model.

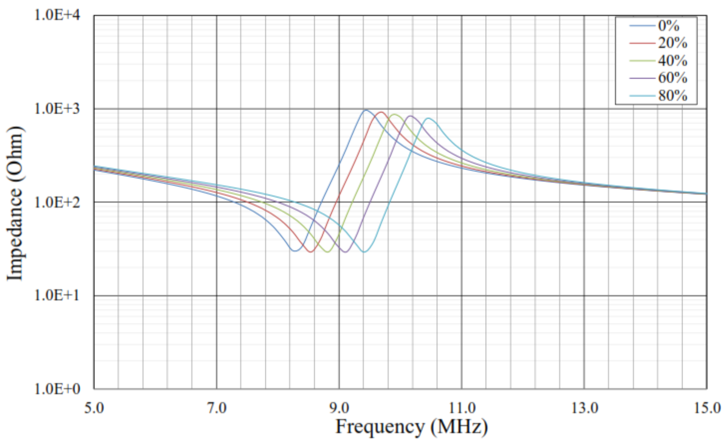

Figure 3. Impedance spectrum of the model with varying glucose concentration

The series and parallel resonance frequency were observed clearly in the phase spectrum of the model. Figure 4 shows the phase spectrum of the model. The series and parallel resonance frequency exist when the phase is zero. From Figure 4, it can be seen that the series resonance frequency when the system filled with water was 8.251×10^6 Hz. The increasing value of the glucose concentration leads to the increased of the series resonance frequency as well as the parallel resonance frequency. It was observed that the maximum phase shift also changed with increasing glucose concentration.

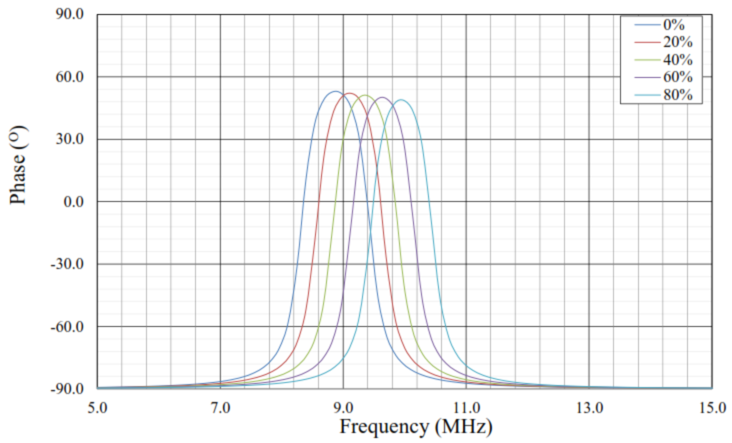

Figure 4. Phase spectrum of the model with varying glucose concentration

The relationship between the glucose concentration and series resonance frequency of the RLC model is depicted in Figure 5. The series resonance frequency was taken at zero phases. The resonance frequency increased with the increasing of the glucose concentration. Frequency change was around 14.8 KHz for every 1% glucose increment. It is expected that using the available frequency counter, the resolution of the glucose concentration change theoretically can be down to 1 ppm level.

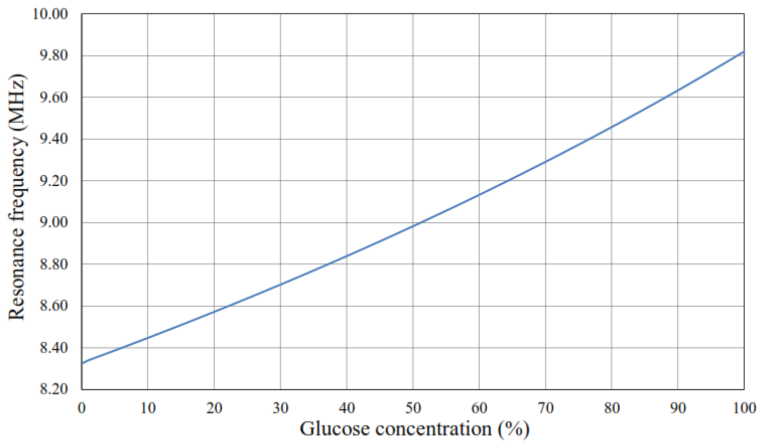

Figure 5. The relationship graphic between changes in resonance frequency to the percentage of glucose in water

4. Conclusion

The series and the parallel resonance frequency of the system model depended on the glucose concentration. In the same condition, the maximum impedance value and the maximum phase shift of the model decreased with the increased glucose concentration. The change of the series resonance frequency which is mainly caused by the permittivity and permeability value of the model increased significantly with the increased glucose concentration. The frequency change of the series resonance frequency was 14.8KHz per 1% glucose concentration.

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